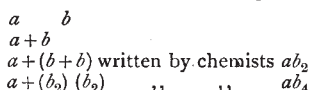


THE METHODS OF INORGANIC EVOLUTION.¹

II.

I HAVE already said that I think most chemists would consider that the formation of larger masses by polymerisation is more probable than by the coming together of dissimilar atoms; but if we consider chemical compounds, certainly the analogy is all in favour of the latter view if the principle of continuity be taken into account, for we are ignorant of the point at which one evolutionary process resigns in favour of another. The present separation of compound from simple bodies is, indeed, simply a measure of our ignorance arising from the feebleness of our laboratory resources in relation to the temperature required to produce more and more simplifications.

I discussed this question in my "Chemistry of the Sun"² in 1887, and showed that the analogy of the completely studied hydrocarbon series beginning with CH₂ suggested a hypothetical elemental sequence.



and so on.

In the concrete hydrocarbon series we have continuous additions of CH₂ to CH₄ until we reach a molecule defined by C₁₆H₃₄, and as the building up of this molecule can be traced without difficulty, so we can imagine it simplified by successive *sheddings* of its constituent CH₂; we pass from a simplification which we can bring about by simple halving to one which provides us with relatively large and small masses.

The next question which arises then is whether there is any way open to us of getting still more light on this matter beyond that furnished by orthodox chemistry.

Let us consider the regions of thought from which we may expect it. To do this, I must go back to my original conclusion derived in 1873 from the spectroscopic facts then accumulated in the work on the sun and stars, and the laboratory observations made to attempt to understand them.

I then wrote:—

"I have asked myself whether all the above facts cannot be grouped together in a working hypothesis which assumes that in the reversing layers of the sun and stars various degrees of 'celestial dissociation' are at work, which dissociation prevents the coming together of the atoms which, at the temperature of the earth and at all artificial temperatures yet attained here, compose the metals, the metalloids and compounds."³

With the progress of science the idea of "atoms" has considerably changed, and this change of view enables us to study the question of dissociation in a more rigid way than was previously possible.

Formerly "atoms" were regarded as merely chemically different from element to element; the recent investigations have introduced a new conception. It is now no longer chemically different matter merely, but matter, whether chemically different or not, *carrying an electric charge*. In the first work along this new line physicists, in order to grapple with the phenomena of electrolysis and solutions, imagined sub-molecules or sub-atoms carrying an electric charge in an electrolyte from the anode to the kathode; this was called an ion (Gr. a goer). This conception has been more recently used to explain those movements of particles of matter which produce light, and therefore spectral lines. The sub-particle, this *ion*, with its electric charge *e* and its mass *m*, is supposed to move in an elliptic orbit under the attraction of a centre. At first the theory supposed the ions to be electrified par-

ticles, but a recent extension considers them to be complex dynamical systems the motions of which are registered by spectral phenomena.

It will be gathered from what I have already said relating to the various questions connected with the study of "series" of spectral lines how the idea of "complex dynamical systems" is also demanded to explain the phenomena presented by them.

Thus I have shown it to be probable that the hydrogen atom which the chemist weighs may be built up of hundreds of the things, call them what you will, a few of which in the hottest stars produce the vibrations which we take as demonstrating the existence of hydrogen in the celestial spaces.

Both these lines of modern evidence tend to justify the view that the different spectra are not produced by different material, but by different conditionings of the same material.

These different conditionings may refer either to the electric charge or to the mass of the ion, or of the molecule round which the ion circulates. The units of matter present in the ion or in the central molecule may vary in number, or their arrangement may vary.

Imagine a series of substances "chemically" different, the intrinsic difference of which really consists merely of their being built up of *different numbers of units*, from A the simplest to Z the most complex. When Z is simplified by heat, its complex system of centre of force and ion with their electric charges will undergo changes which we may expect to result in the formation of less complex systems doubtless built on a like pattern, and therefore capable of producing spectra; hence we are bound to see the spectra of some of the intermediate forms which, when they are stable and go about in company, it may well be that physicists have already recognised. These we may call B or C, or R or S, or X or Y, as representatives of various complexities.

The more complex the form experimented on and the higher the temperature employed in the laboratory, the more spectral lines indicating different chemical "elements" in intermediate stages may we see.

I say in the laboratory because in the stars the result will be different. There, in consequence of the long continued action of heat and the shielding of the reversing layer from the effects of lower temperature, we may only see at the highest temperature the spectra of the forms A and near A. We now know what these are.

To take another case, let us assume that the electric charges or arrangement as well as the number of the units of matter may vary. Under these conditions, when we dissociate Z, not all, but only some, of possible intermediate forms may be expected to afford spectral evidence. Say, to take an example, those in the vertical columns of Mendeléeef's table, and I am led to make this suggestion because Kayser has shown that in "series" the duplicity or triplicity of lines is associated with the position of the elements producing them in these columns. A concrete case would be afforded by contrasting the behaviour of sodium and caesium, representing relatively simple and complex substances. We might observe the lines of sodium when caesium is dissociated; we should not expect to see the lines of caesium when sodium is dissociated.

The two cases taken it is possible may illustrate the difference between related and not related groups of "elements."

The apparently constant appearance of representative lines of the spectrum of one substance of a group in that of the other member of the same group may be thus explained, although it has generally been attributed to the presence of impurities, as in the case of all common long lines seen in spectra; and this in spite of the pro-

¹ Continued from p. 131.

² P. 263 *et seq.*

³ Bakerian Lecture, 1873 (*Phil. Trans.*, clxiv. Part 2, p. 49t).

test that if the purest specimens known (I have worked on beads of Stas' silver which had never been touched) were so impure, some of the decimals used to express their atomic weight might be well spared. But it is not a question of apparent impurities only.

It is possible that some of the gases of lower atomic weight which exist in the hottest stars may be represented by A in opposition to heavy metals represented by Z, the existence of which is known in the cooler stars only.

The giving off of gases from metals when high tension electricity is employed is well known. This has been explained by assuming them to be "furnace gases," that is, gases "occluded" by the metals during their reduction. But this does not seem to be a sufficient explanation, for the same gases are given off by meteorites. We now see why something like this may happen if there is any foundation for the modern conception of the structure of the "atom"; and do not these facts explain the chemistry of the hottest stars?

It is too early yet to attempt to discuss the effects of the electric charge in this connection, but it must be pointed out that so soon as the ions, however associated their units may be, which are supposed always to have an electric charge upon them, are subjected to the action of a voltaic or induced current, the spectral phenomena observed when they are heated are liable to great changes in some cases, and especially when high atomic weights are in question. Doubtless we have here a field of research which will ultimately supply us with the most precious knowledge. I have already shown that with the gases, such as hydrogen and oxygen, heat alone gives rise to no spectral phenomena, while in the case of such metals as sodium heat is so effective in its dissociating power that the subsequent application of electricity produces no further change.

We have, in fact, to consider that the effects produced on different substances under the same conditions may be different, and that the stars carry us further than our laboratories; that there are stages of spectral change within and beyond our experimental powers revealing a *shedding* of ions at different temperatures.

Dr. Preston's Researches.

Quite recently the study of magnetic perturbations of spectral lines has brought a fresh array of evidence on this question.

It has now been proved that spectral phenomena are different when the light source under examination is subjected to the action of a strong magnetic field which, among other things, causes a precessional movement of the orbits of the ions to which I have already referred.

In order to consider the bearing of this, let us deal with the spectrum of zinc which contains triplets. It has been shown that denoting these in ascending order of refrangibility by $A_1, B_1, C_1, A_2, B_2, C_2$, &c., the lines A_1, A_2 , &c., show the same magnetic effect in character, and have the same value of e/m . The lines B_1, B_2, B_3 , &c., and C_1, C_2, C_3 , &c., form other series, and possess a common value for the quantity e/m in each case.

Dr. Preston, one of the most successful workers in this new field, states:—

"The value of e/m for the A series differs from that possessed by the B series, or the C series, and this leads us to infer that the atom of zinc is built up of ions which differ from each other in the value of the quantity e/m , that each of these different ions is effective in producing a certain series of lines in the spectrum of the metal."

But this is by no means all that is to be learned from Dr. Preston's researches. He writes:—

"When we examine the spectrum of cadmium or of magnesium—that is, when we examine the spectra of other metals of the same chemical group—we find that not only are the spectra homologous, not only do the

lines group themselves in similar groups, but we find in addition that the corresponding lines of the different spectra are similarly affected by the magnetic field. And further, not only is the character of the magnetic effect the same for the corresponding lines of the different metals of the same chemical group, but the actual magnitude of the resolution as measured by the quantity e/m is the same for the corresponding series of lines in the different spectra. This is illustrated in the following table, and leads us to believe, or at least to suspect, that the ion which produces the lines A_1, A_2, A_3 , &c., in the spectrum of zinc is the same as that which produces the corresponding series A_1, A_2, A_3 , &c., in cadmium, and the same for the corresponding sets in the other metals of this chemical group. In other words, we are led to suspect that, not only is the atom a complex composed of an association of different ions, but that the atoms of those substances which lie in the same chemical group are perhaps built up from the same kind of ions, or at least from ions which possess the same e/m , and that the differences which exist in the materials thus constituted arise more from the manner of association of the ions in the atom than from differences in the fundamental character of the ions which build up the atoms."

Magnetic effect.	Nonets or complex triplets.	Sextets.	Triplets.
Cadmium ... $\lambda =$	5086	4800	4678
Zinc ... $\lambda =$	4811	4722	4680
Magnesium ... $\lambda =$	5184	5173	5167
Precessional spin ...	$\frac{e}{m} = 55$	$\frac{e}{m} = 87$	$\frac{e}{m} = 100$

[This table shows the effect for the three lines which forms the first natural triplet in the spectrum of cadmium compared with the corresponding lines in the spectrum of zinc and magnesium. It will be seen that the corresponding lines in the different spectra suffer the same magnetic effect both in character and magnitude. Thus the corresponding lines 4800, 4722, 5173 are each resolved into sextets, and the rate at which the ionic orbit is caused to precess is the same for each (denoted by $e/m=87$ in the table). Similarly for the other corresponding lines.]

This is a result of the first order of importance. I previously discussed what might be expected to happen if the complex system giving the spectrum of an element were *broken up*, and showed that if less complex systems of the same pattern—that is, consisting of centre of force and ion with its electric charge—were thus produced, these systems would be just as capable of giving spectra as the one the breaking up of which produced them. We should get new ions free to move and vibrate, and new spectra which may reveal the constituents, that is, the manner in which the complex system breaks up. But Dr. Preston goes further than this. He shows that the same ion associated with different centres of force gives us lines at different wave-lengths. That a certain ion which in the spectrum of magnesium gives rise to δ is also present in zinc and cadmium, though there is no trace of δ in their spectra.

Now, if the views held by those who have worked along any of these lines be confirmed, we shall be compelled not only to give up polymerisation as the only cause of greater complexity of the molecules of the elements, but to acknowledge a great strengthening of the view that all chemical atoms have a common basis, and build new mental images on this basis. I now pass from the spectroscopic evidence to work in a new field.

Prof. J. J. Thomson's Researches.

I have before referred to the fact that science now has to consider masses much smaller than the atom of hydrogen. This we owe not only to a discussion of the phenomena of series but also to some recent researches of Prof. J. J. Thomson, made in connection with his work on the cathode rays.

Since the kathode rays produce luminous effects their path can be traced, hence it is known that they are deflected in a magnetic field. This deflection depends upon the mass of each particle and the electric charge it carries, that is, upon their ratio, m/e . This ratio Prof. J. J. Thomson finds to be about one-seven-hundredth of the corresponding value for the hydrogen ion in ordinary electrolysis.

At the same time it has been found by Prof. J. J. Thomson and Mr. Townsend that the electric charge e is the same for kathode rays and a hydrogen ion. The m/e in fact may be regarded as independent of the nature of the gas. Since then the m/e of the hydrogen ion is 700 times greater than in the case of kathode particles, the m , the smallest mass whose existence Prof. J. J. Thomson has glimpsed, can only be about one-seven-hundredth of the hydrogen ion.

Prof. J. J. Thomson writes:—¹

"The explanation which seems to me to account in the most simple and straightforward manner for the facts is founded on a view of the constitution of the chemical elements which has been favourably entertained by many chemists; this view is that the atoms of the different chemical elements are different aggregations of atoms of the same kind. In the form in which this hypothesis was enunciated by Prout, the atoms of the different elements were hydrogen atoms; in this precise form the hypothesis is not tenable, but if we substitute for hydrogen some unknown primordial substance X, there is nothing known which is inconsistent with this hypothesis, which is one that has been recently supported by Sir Norman Lockyer for reasons derived from the study of the stellar spectra."

* * * * *

"Thus on this view we have in the kathode rays matter in a new state, a state in which the subdivision of matter is carried very much further than in the ordinary gaseous state: a state in which all matter—that is, matter derived from different sources such as hydrogen, oxygen, &c.—is of one and the same kind, this matter being the substance from which all the chemical elements are built up."

* * * * *

"The smallness of the value m/e is, I think, due to the largeness of e as well as the smallness of m . There seems to me to be some evidence that the charges carried by the corpuscles in the atom are large compared with those carried by the ions of an electrolyte."

Thus the whole question of dissociation has been advanced because while on the chemical view we have to deal with intrinsically different kinds of matter from element to element, on the view of Prof. J. J. Thomson m is a constant for every element, reminding one of Rydberg's general formula for series in which N_0 is practically a constant for every element, although Rydberg acknowledges slight variations which may be due to errors of observation.

Prof. J. J. Thomson is thus led to the following view of the differences in construction of a simple "atom" and a compound "molecule":

"In the molecule of HCl, for example, I picture the components of the hydrogen atoms as held together by a great number of tubes of electrostatic force; the components of the chlorine atom are similarly held together, while only one stray tube binds the hydrogen atom to the chlorine atom."

Dr. Preston's results on the magnetic perturbation of lines, to which I have already referred, leads him to the same general conclusions as those arrived at by Prof. J. J. Thomson in favour of the view of dissociation. He says:—

"It may be, indeed, that all ions are fundamentally the same, and that differences in the value of e/m , or in the character of the vibrations emitted by them, or in

the spectral lines produced by them, may really arise from the manner in which they are associated together in building up the atom."

And again:—

"We have, I think, reasonable hope that the time is fast approaching when intimate relations, if not identities, will be seen to exist between forms of matter which have heretofore been considered as quite distinct. Important spectroscopic information pointing in this same direction has been gleaned through a long series of observations by Sir Norman Lockyer on the spectra of the fixed stars, and on the different spectra yielded by the same substance at different temperatures. These observations lend some support to the idea, so long entertained merely as a speculation, that all the various kinds of matter, all the various so-called chemical elements, may be built up in some way of the same fundamental substance"

The Three Ways of Inorganic Evolution.

At the present time, then, we have before us three suggested ways of inorganic evolution.

Taking the chemical view, this may depend on

(1) Polymerisation, or the combination of similar chemical molecules, or

(2) The combination of dissimilar chemical molecules.

In the new physical view all this is changed into

(3) The gradual building up of physical complexes from similar particles associated with the presence of electricity.

In this last conception we have the material world, up to the highest complex, built up of the same matter under the same laws; as in spectrum analysis there is no special abrupt change between the phenomena presented by the simple and compound bodies of the chemist, so also in the new view there is no break in the order of material evolution from end to end.

Certainly the new view seems competent to throw light on many facts which lacked explanation on the old one, by whatever method of evolution the higher complexes were assumed to be brought about. Because on the ionic theory we can imagine several first forms, so that the question of *descent* comes later with the introduction of more complex systems. These various first forms bring about the possibility of evolution along several parallel lines, as well as of the possibility of an infinite number of intercrossings. In this connection we must not forget that the constituents of the reversing layer of Bellatrix and of protoplasm are nearly identical, while the particular forms of matter of which they are composed make so little show in the sun.

The analogy before suggested between the earth and moon, and the central congeries of material units and the ion revolving round it, suggests that the ion may be the more constant in its structure, and that it is to a large extent to the varying mass charge representing the centre of force that spectral changes are due. It may be that the subordinate "series" indicate that very small variations of complexity are possible, as well as greater ones.

In the light of this analogy, the ions visible in the simple spectra of the hottest stars are those associated with the smallest centres of force. These are, so far as we know at present, hydrogen, helium, asterium, oxygen and nitrogen among the gases; carbon and silicium, and calcium, magnesium and sodium among the metals, in the forms we study by their spectra at the highest temperatures we can employ in our laboratories.

As the stars cool larger aggregates of material units in the centres of force round which these ions revolve become possible, and hence the complexity of the spectrum of Uranium and of the sun, representing a cool star, are both explained by the same process, the various stages of which can be reproduced in the reverse direction by various degrees of dissociation.

NORMAN LOCKYER.

¹ *Phil. Mag.*, vol. xlv. p. 311, October 1897.